A Unique 520–590 GHz Biased Subharmonically-Pumped Schottky Mixer

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***Abstract*—We report on the design and performance of a novel broadband, biased, subharmonic 520–590 GHz fix-tuned frequency mixer that utilizes planar Schottky diodes. The suspended stripline circuit is fabricated on a GaAs membrane mounted in a split waveguide block. The chip is supported by thick beam leads that are also used to provide precise radio frequency (RF) grounding, RF coupling and dc/intermediate frequency connections. At room temperature, the mixer has a measured double sideband noise temperature of 3000 to 4000 K across the design band.**

***Index Terms*—Schottky diode mixers, submillimeter wave diodes, submillimeter wave mixers.**

I. Introduction

THERE is a demand for heterodyne receivers operating in the submillimeter band above 300 GHz for spectroscopic instrument applications, especially for space-borne instruments. Near term deep space missions employing such receivers include a proposal for water and volcanic emission detection observations on Mars and for measurements of atmospheric trace gases and gas dynamics at Venus. Due to the extreme size and weight constraints of such planetary missions, it is highly desirable to use un-cooled mixers at the heart of such receivers. The Schottky mixer is currently the only sensitive un-cooled heterodyne sensor available in this frequency range.

The circuit topologies used in submillimeter wave Schottky mixers can be categorized into several types. Two types of fundamental mixers are the single-diode mixer [1], [2] and the balanced fundamental mixer [3, p 292]. The balanced topology has been used for SIS mixers [4] and recently, by the authors, for a Schottky mixer [5].

A third mixer type is the X2 harmonic mixer, which uses a local oscillation (LO) frequency of half the radio frequency (RF). Hence, it is sometimes known as a "subharmonically-pumped" mixer, commonly shortened to "subharmonic mixer." These have been used in the millimeter and submillimeter range for more than two decades [6]–[8]. To improve the utility and performance of submillimeter Schottky subharmonic mixers we have designed, fabricated, and assembled a new type of biased, wide-LO-range (around 15%), mixer using planar Schottky technology. The bias allows a much wider range of LO powers to pump the mixer, which is an important consideration, since the output power of widely tunable LO sources often varies greatly across the band. The mixer also requires no mechanical tuning to change frequency.

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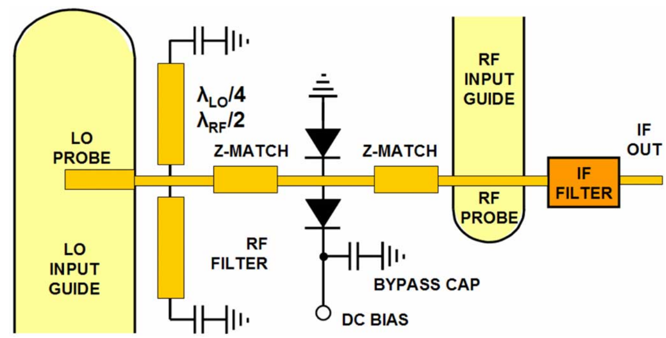

Fig. 1. Circuit of subharmonically-pumped mixer.

II. Design Method and Fabrication

The circuit topology is shown schematically in Fig. 1. The diodes are connected at RF and LO as a shunt anti-parallel pair between the center line and ground. One ground connection is made via a bypass capacitor that allows the dc bias voltage to be applied to the diodes. Note that by biasing the IF port, the two diodes can be biased at different current levels. The LO is brought from the left, the RF from the right, and the IF output is taken from the RF side through a filter that blocks both RF and LO. Between the LO guide and the diodes is a pair of shunt quarter-wave stubs that act as an RF filter, preventing RF leakage into the LO input. More details on the design are given in [9].

The mixer was designed using a combination of nonlinear harmonic balance circuit analysis software and finite element passive circuit analysis, similar to that used previously for varactor multiplier design [10]. The mixer analysis is based on [11], [12] and extended using [13], [14], and takes into account the nonlinear junction impedance and series resistance.

The design itself starts with an optimization of the diode size and terminating impedances based on the available LO pump power. The heart of the mixer, including the diode pair and bias capacitors, is then analyzed in the block using Ansoft HFSS. The waveguide block circuitry is modeled as transmission lines and waveguides in a commercial linear circuit simulator. The circuit is adjusted to present the desired optimum embedding impedances to the diode junctions, then incrementally more and

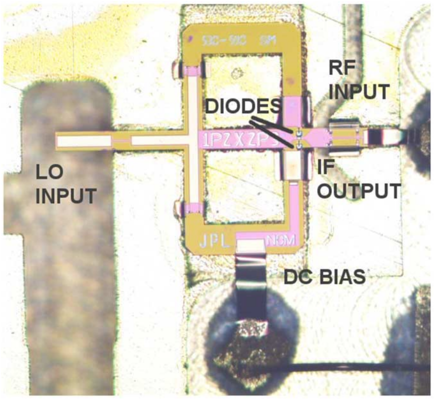

Fig. 2. Subharmonic mixer mounted in block.

more of the circuit is analyzed using HFSS until the full circuit is verified.

The harmonic balance software and diode model have been developed at JPL to allow advanced diode noise properties such as undepleted epi-layer electron heating to be included in the analysis in addition to the usual nonlinearities, resistive noise, and shot noise. Using a device Monte Carlo calculation similar to that in [15], the undepleted epi-layer was found to be nearly homogeneous in temperature during the LO cycle. The heating of this region over the LO cycle was modeled using a balance equation [16] method and the substantial heating effects included in the model.

The circuits were fabricated using the JPL planar diode process including beam leads. Beam leads are critical to coupling the signals to and from the waveguides, as well as in the dc and IF connections and grounding of the diodes and bypass capacitors. The circuit substrate is a 5-μm thick GaAs membrane. Multiple metallization processes are employed for the on-chip capacitors and diodes [17]. The completed circuit inside the waveguide block is shown in Fig. 2.

III. Mixer Measurements

The mixer performance is measured using an automatic Y-factor system specifically assembled for submillimeter wave mixers. It incorporates two resistive-foam lined cavities as the hot and cold loads; the cold load is dipped in LN2, while the hot load is held at room temperature. These are alternately presented to the mixer input horn, with the IF output going through isolators, amplifiers and filters to a microwave power meter. The system is calibrated by an internal hot/cold load system, and the entire setup is operated by a computer running specially developed software for control and calculation of noise temperature and conversion loss. The mixer is pumped with an LO source consisting of either a 120 to 140 GHz Gunn source pumping a doubler, or an amplified Agilent W-band source pumping a $\times 2 \times 2$ multiplier chain. The LO source power is measured using an Erickson Instruments Inc. calorimeter power meter [18]. These power measurements should be considered approximate due to the fact that the mixer presents a different termination to the output tripler than the power meter, and the tripler output is sensitive to its terminating impedance.

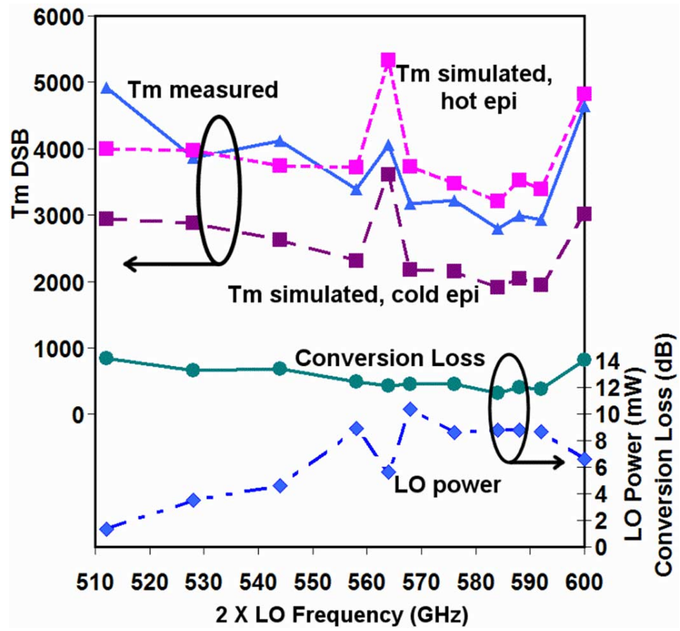

Fig. 3. Mixer performance variation with LO frequency.

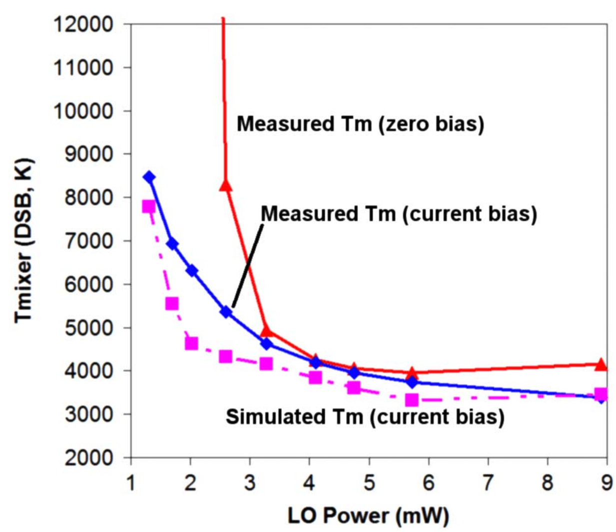

Fig. 4. Mixer noise versus LO power at LO frequency of 280 GHz.

The measured effective double sideband (DSB) noise temperature, T_m, and conversion loss of the mixer as a function of LO frequency is shown in Fig. 3. The measurements cover the design bandwidth from 530 to 590 GHz, and indicate the wide RF bandwidth of the mixer. Also depicted in the figure are the harmonic balance simulation results; those including hot-electron effects are indicated as "hot epi" [19] and the equivalent simulation results without electron heating are indicated as "cold epi." The hot electron results clearly simulate the performance more accurately.

The performance of the mixer as a function of LO power is indicated in Fig. 4. The performance is measured with both a close-to-optimum current bias at each power level, as well as with zero voltage bias simulating a standard subharmonic mixer bias. The current bias levels range from 0.2 mA at the lowest

LO power, to 0.6 mA at the highest. The improvement in performance of the mixer with bias compared to that of a standard "zero-bias" subharmonic mixer is quite clear.

Several things are notable in Fig. 4. As LO power is reduced, the zero bias mixer stops working at a little below 3 mW, whereas the biased mixer performance degrades gradually, remaining below 9000 K with LO power as low as 1.2 mW. At higher LO power, the zero bias mixer noise starts to increase again due to increasing hot electron noise generated by the rectified LO signal current [14, Fig. 5]. Biasing the mixer allows this current to be kept low so the mixer noise continues to decrease as LO power goes up.

As earlier, the simulated performance is also included. Here it is clear that the departure of simulated from measured performance is greater at lower LO power. Further simulations and comparisons with measurements indicate that there are probably at least two factors that explain the difference. One is the variation of LO power with the last LO multiplier pumping the mixer, compared to being terminated by the power meter. This variation may be exacerbated at low LO power since the mixer likely presents a load quite different than the power meter at low pump power levels.

Another factor is that the two diodes in the mixer are not pumped exactly equally, due to phase and amplitude differences in the LO coupling to the diodes. The current version of the simulator assumes equal LO pumping of the diodes though differences in the RF coupling are included. This effect is likely worse at low LO power when the diodes are farther from pump saturation. The performance could be improved by carefully biasing the diodes to separate current levels, rather than equal currents as in these measurements.

IV. Conclusion

In recent years, advances in circuit analysis software and semiconductor processing technology have allowed the design and fabrication of submillimeter/terahertz circuits that were almost impossible to produce previously. Schottky mixers have heretofore been narrow band and difficult to produce, requiring painful external tuning and whisker adjustment to achieve their design objectives.

This mixer is the first design of its type in this frequency range, and achieves a DSB noise temperature below 4000 K across almost the entire band after the first iteration.

This performance makes it, and similar mixers covering other bands, appropriate to be the heart of an extremely wideband spectroscopic sensor. The room temperature operation and high sensitivity will allow such spectrometers to open up a new class of observational instruments.

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